

A Novel Reversible Watermarking Method based on Adaptive Thresholding and Companding Technique

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Abstract—Embedding and extraction of a secret information as well as the restoration of the original un-watermarked image is highly desirable in sensitive applications like military, medical, and law enforcement imaging. This paper presents a novel reversible data-hiding method for digital images using integer to integer wavelet transform and companding technique which can embed and recover the secret information as well as can restore the image to its pristine state. The novel method takes advantage of block based watermarking and iterative optimization of threshold for companding which avoids histogram pre and post-processing. Consequently, it reduces the associated overhead usually required in most of the reversible watermarking techniques. As a result, it keeps the distortion small between the marked and the original images. Experimental results show that the proposed method outperforms the existing reversible data hiding schemes reported in the literature.

Keywords—Adaptive Thresholding, Companding Technique, Integer Wavelet Transform, Reversible Watermarking

I. INTRODUCTION

DIGITAL image watermarking hides useful information in the image mostly pertaining to the content creator or owner for the purpose of content authentication or copyright protection [1]. However, this information hiding has one common limitation that the original image is inevitably distorted due to the information embedding. This distortion can not be removed completely due to quantization [2, 3], bit-replacement [4, 5], or truncation [6, 7]. Although distortion is often quite small and various perceptual models [8, 9] are used to minimize its visibility, but the distortion might not be acceptable for certain applications which have sensitive imagery, like medical and military applications. In medical imaging, any modification to the original image may affect a physician's diagnosis and lead to legal problems [10, 11]. In military imaging, images are viewed under non-standard conditions (e.g. extreme enhancement and zoom) thus adding a noise like signal in the form of watermark is unacceptable [12].

As such reversible watermarking which embeds information in images in a reversible manner can be used.

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Once the image authentication system decides the image to be authentic, the watermarking process is reversed to get the original image. In this regard, Tian has presented a high-capacity approach based on expanding the pixel intensity difference between neighboring pixels [13]. This method allows one bit to be embedded in every pair of pixels. Xuan et al. [14] have presented a lossless data hiding method using integer wavelet transform (IWT) and threshold embedding technique. Data is embedded into the least significant bit-plane (LSB) of high frequency coefficients whose magnitude is smaller than a certain pre-defined threshold. Histogram modification is applied as preprocessing step to prevent overflow/ underflow. In another work, Xuan et al. [15] have used the companding technique, which is based on the compression and expansion of the wavelet coefficients. The schemes described above in [14, 15] have one drawback in common that these schemes need to apply histogram modification as a preprocessing step to prevent the overflow/underflow problem. This modification not only increases computational cost but also increases payload overhead for keeping track of spatial locations where the pixels were modified in the image during histogram modification. Further, in conventional reversible watermarking schemes, high embedding capacity without degrading the image quality can not be sufficiently achieved, so more advanced reversible watermarking schemes are needed. In this paper, a new high capacity reversible watermarking method based on adaptive thresholding (AT) and companding technique is introduced. It improves upon the fixed thresholding (FT) method by introducing block based embedding and consequent optimization of the threshold for each block. In this way, the proposed method exploits the local block based distribution of high frequency contents which allows embedding of significantly a larger payload for the same imperceptibility level than the FT scheme. Further, the proposed method does not require histogram modification to prevent underflow/overflow unlike FT scheme. This is because the conditions of overflow/underflow are being implicitly tackled in the iterative optimization of the block based thresholding.

II. FIXED THRESHOLD BASED COMPANDING

Companding is the process of compressing a signal followed by expanding it. Let K be a compression function and E be an expansion function. For a signal f , K and E have the following

relationship: $E(K(f)) = f$. For digital signal, K_q and E_q represent the quantized versions for K and E respectively and q denotes the quantization function. The compression function K_q is given by:

$$f_q = K_q(f) = \begin{cases} f & |f| < T \\ \text{sgn}(f) \times \left(\left\lfloor \frac{|f| - T}{2} \right\rfloor + T \right) & |f| \geq T \end{cases} \quad (1)$$

where $\text{sgn}(\cdot)$ is the sign function and T is a pre-defined fixed threshold. The expansion function E_q is given by:

$$E_q(f) = \begin{cases} f & |f| < T \\ \text{sgn}(f) \times (2|f| - T) & |f| \geq T \end{cases} \quad (2)$$

Companing values via equations (1) and (2) produce no error if $|f| < T$. However when $|f| \geq T$, the companing error is produced:

$$Z = |f| - |E_q(K_q(f))| \quad (3)$$

where $Z \in \{0,1\}$

A simple realization of Companing based watermarking technique is as follows:

- 1) Compression function K is applied to the original signal f to obtain a new signal $h=K(f)$. Assume the binary expression of h is $p_1p_2\dots p_n$, where $p_i \in \{0,1\}$.
- 2) A bit $b_i \in \{0,1\}$ is appended after the least significant bit (LSB) of h . In this way, h becomes $h' = p_1p_2\dots p_nb$ which can mathematically be expressed as: $h' = 2 \times h + b$
- 3) In the data extraction stage, we only need to extract the LSB bit from the received signal h' , which means $b = \text{LSB}(h')$. The signal h can thus be recovered by the expression $h = \frac{h' - b}{2}$.
- 4) After obtaining the signal h , we can recover the original signal by expression $f = E_q(h) + Z$, where Z is companing error.

III. PROPOSED SCHEME

The proposed method employs block based embedding as against the whole image based embedding mechanism. The threshold for each block is determined adaptively by creating a threshold map that consists of thresholds one for each block.

A. Generating threshold map (T_{MAP})

Before embedding the actual watermark, the proposed method adaptively computes the threshold for each block based on its properties. The block diagram for finding the T_{MAP} is shown in Fig. 1 and described as follows:

Initialize T_{MAP} to an $(M/B) \times (N/B)$ zero matrix, where B is the user defined size of block and M, N are the height and width of the input image respectively. Initialize T_{INIT} , T_{MIN} and $PSNR_{MAX}$ with the user defined values. Set value of T as

T_{INIT} . Divide the input image I into blocks of size $B \times B$. Compute IWT of each block using Cohen-Daubechies-Faurae CDF(2,2) filters with decomposition up to 2nd level for obtaining middle and high frequency wavelet components. Apply the compression function using equation (1) on all horizontal, vertical and diagonal sub-band coefficients that are less than T . Embed the watermark in all sub-band coefficients irrespective of T using equation $h' = 2 \times h + b$, where h represents the original coefficient while b is watermark bit to be embedded. Compute the inverse IWT of block(i,j) to obtain block' (i,j) where i, j are row and column indices of a block respectively. In order to check that watermark embedding has not caused overflow/underflow, minimum and maximum values of watermarked block are calculated and are checked as under:

$$\text{block}^*(i,j) = \begin{cases} \text{embedable} & \text{if } \min(\text{block}'(i,j)) \geq 0 \\ & \text{AND } \max(\text{block}'(i,j)) \leq 255 \\ \text{not embedable} & \text{otherwise} \end{cases} \quad (4)$$

The $PSNR$ of block*(i,j) is computed if it is embeddable. If $PSNR$ is found to be greater than or equal to maximum allowed $PSNR_{MAX}$, the threshold T is recorded in T_{MAP} . Now decrease the value of T by 1. This decrement in T will increase the $PSNR$ of the block after embedding the watermark. This is due to the fact that when T is small, more and more coefficients are companed and therefore, overall embedding distortion will be small and good visual quality of marked image is achieved. The iteration will continue till T equal to T_{MIN} , at which point we obtain the matrix T_{MAP} containing threshold values of each block of input image I depending upon the properties of that block.

B. Watermark Generation

The proposed scheme generates the watermark from the following components:

(a) *The error vector (Z)*: If the value of coefficient is greater than or equal to user defined threshold, it is compressed (equation 1) and then expanded (equation 2). To be able to recover the original image exactly, it is necessary to collect the companing errors (equation 3). These errors are accumulated in vector Z .

(b) *Payload (P)*: this represents user defined information which can be any secret information related to image.

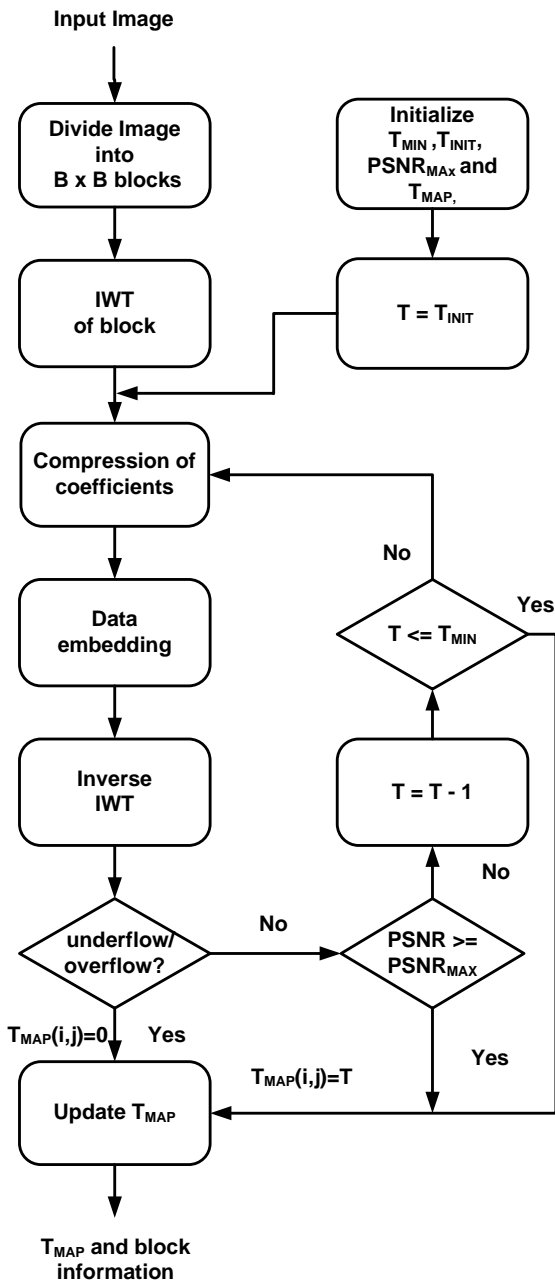


Fig. 1 The block diagram of the algorithm for finding threshold map

The overall watermark W will be combination of the E and P . In order to reduce the size of W , it is losslessly compressed using arithmetic encoding.

C. Watermark embedding

Divide the input image I into blocks of size $B \times B$. Compute the 2D IWT of each block (i,j) upto level 2. Obtain the threshold $T(i,j)$ from T_{MAP} for the corresponding block (i,j) . Apply the compression function on the coefficients of each sub-band (HL_1, LH_1, HH_1) based on the threshold $T(i,j)$. Now

embed the watermark W into block (i,j) using equation $h' = 2 \times h + b$. Compute inverse IWT to get the watermarked block $block'(i,j)$. The process continues until W is completely embedded into the blocks. T_{MAP} also needs to be embedded in the image to facilitate recovery. This is because embedding has been performed in each block with a different threshold. Hence T_{MAP} is compressed using arithmetic encoding to reduce its size significantly. Finally, compressed T_{MAP} is embedded in level 2 coefficients (HL_2, LH_2, HH_2) irrespective of blocks using T_{MIN} . Other information embedded along with T_{MAP} is the size of block i.e B . The marked image I' thus obtained is the final watermarked image.

D. Watermark Extraction

Compute 2D IWT of image I using CDF filters and decompose the image upto level 2 to obtain HL_2, LH_2 and HH_2 wavelet sub-bands. Using the known threshold value of T_{MIN} extract the computed T_{MAP} and block size information using the relation $b = LSB(h')$. Uncompress T_{MAP} related information to find T_{MAP} and block size. Initialize B with block size information. Divide the watermarked image I' into $B \times B$ size blocks. Now compute the IWT of each block (i,j) and perform decomposition upto level 1. For each block (i,j) find the corresponding threshold $T(i,j)$ from T_{MAP} . Extract the watermark from the wavelet coefficients of each block using $b = LSB(h')$. Accumulate all least significant bits used earlier to recover the watermark bitstream W' . Decompress the bitstream W' using arithmetic decoding algorithm to restore the original bitstream. Once W' has been decompressed, the error vector Z' and payload P' can easily be recovered. Restore coefficients by using equation, $h = \frac{h' - b}{2}$. Obtain the original coefficients by using equation $f = E_q(h) + Z$. The original image is then obtained by taking the inverse IWT of restored coefficients.

IV. EXPERIMENTAL RESULTS

In our experiments, standard images of Lena and Baboon with size 512×512 are used. The original and watermarked versions of these images are shown in Fig. 2. The fixed values of T_{MIN} and $PSNR_{MAX}$ are heuristically set to 2 and 42.0 dB, respectively. However, the value of T_{INIT} is selected in the range of $\{2-15\}$. The value of $PSNR_{MAX}$ can be varied as per desired level of imperceptibility used in a particular application. The value of $PSNR_{MAX}$ directly controls the quality of watermarked image. For watermarked images shown in Fig. 2, the initial threshold (T_{INIT}) is used as 15 and a block size is set to 8×8 . Table I compares the performance of proposed method with that of FT scheme for Lena and Baboon images, respectively. The proposed method provides better imperceptibility in terms of PSNR for the same payload. This margin of improvement is clearly visible at low and high payloads. The difference or improvement is more in case of textured images. This is because, the embedding is performed in high frequency which gives more embedding space in

textured images and therefore is well exploited by the local adaptation of the companding threshold.

Finally, we compare the proposed method with some other techniques of reversible watermarking reported in the literature. These include difference expansion (DE) method of Tian [13], FT method of Xuan [14], Companding and FT method of Xuan [15], and Reversible watermarking Technique of Fraser [12]. The graph shown in Fig. 3 shows that proposed method outperforms the existing approaches.

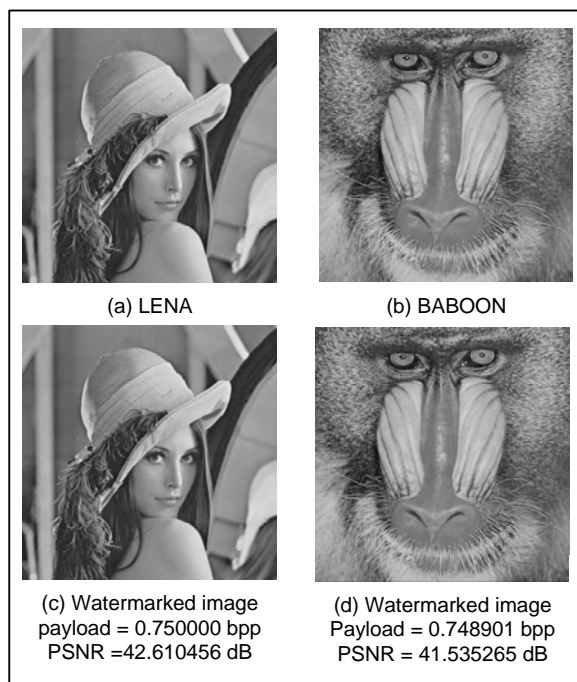


Fig. 2: (a) and (b) Original images (c) and (d) watermarked images

V. CONCLUSION

We have proposed a reversible watermarking system based on companding and adaptive thresholding. The proposed method has potential applications in military, medical, and lawenforcement related image processing. By taking advantage of block based watermarking and iterative optimization of threshold for companding, histogram pre and post-processing has been avoided which is usually required in number of reversible watermarking techniques reported in literature. The embedding and extraction processes of proposed method are simple and computationally efficient. The method can easily be employed in real time applications.

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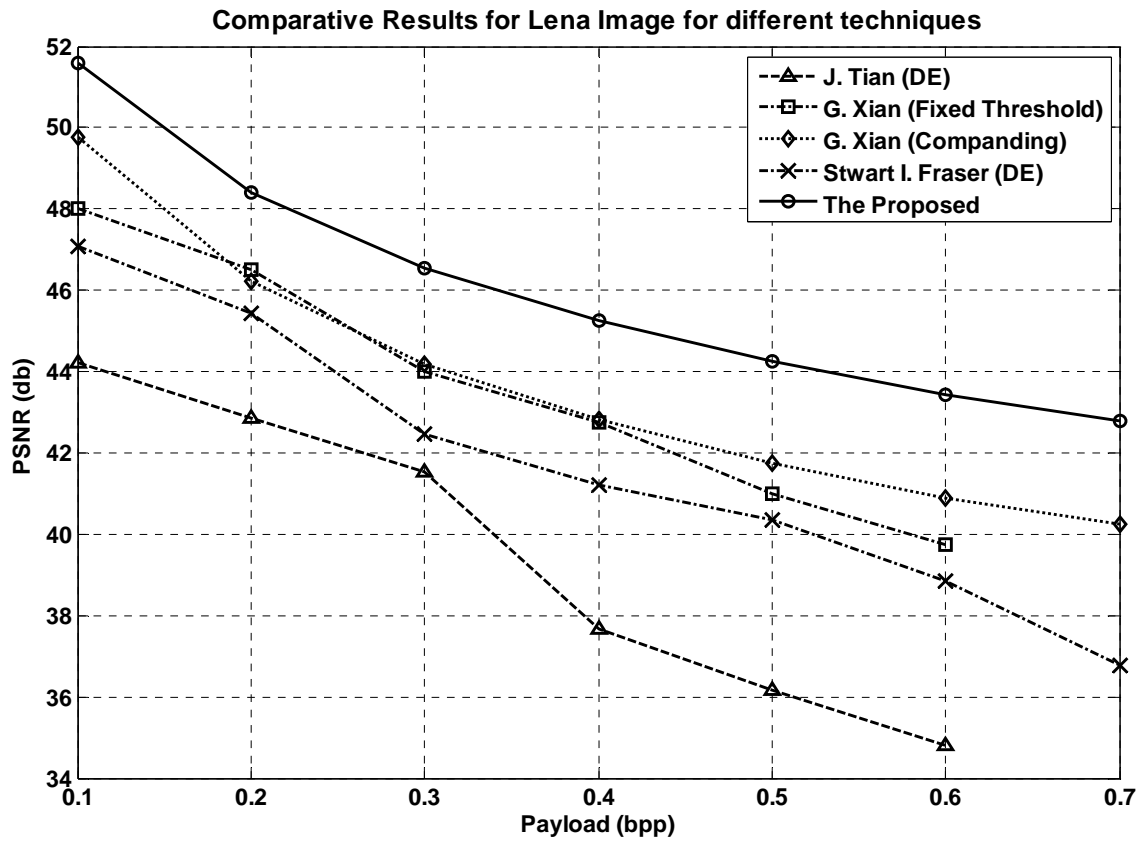


Fig. 3 Comparison of proposed technique with some other reversible watermarking techniques